Optical Communications Links Using Entangled Two-Photon Light Sources

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Outline

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- Outline
- Motivation
- Quantum Lithography beat Rayleigh diffraction limit
- Received Power Law
- Impact of entangled-photons
  - Noise entangled-photons
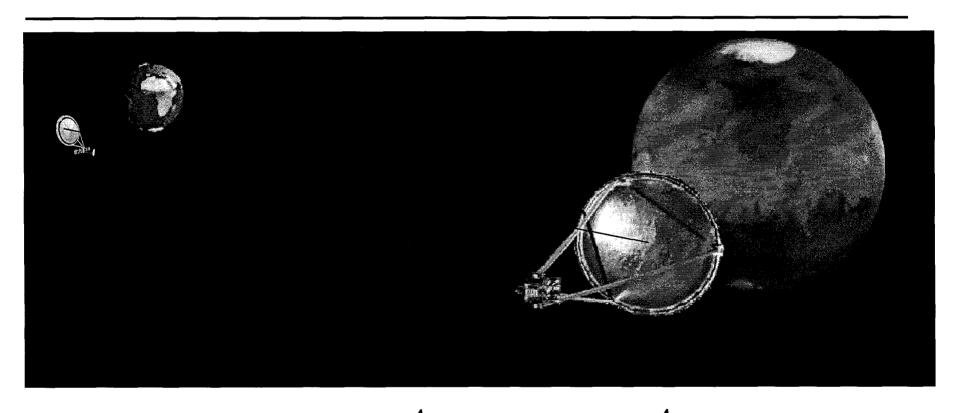 - Rayleigh diffraction limit
- Conclusions

Motivation

Robert L. Forward:

- saw results from quantum lithography

- Suggested JPL's Quantum Computing Technologies Group investigate whether entangled photons improve

  - light sail propulsion
  - optical communications link performance

Explore unique feature of entangled photons that can be exploited in communications applications.

Received Power Law

$$P_r = P_t \frac{A_t}{R^2} L_{Atmos} \mu \frac{A_r}{\lambda^2}$$
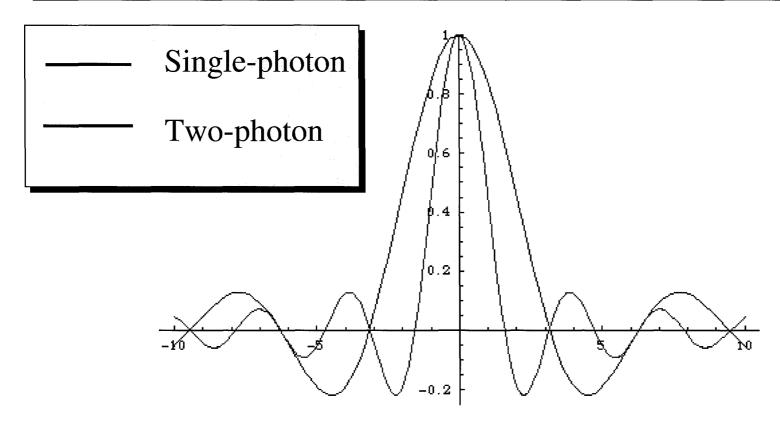
Rayleigh Diffraction Limit

Classical Diffraction Law:

$$D_r = \frac{2.44\lambda}{d_t} R$$

Two-Photon Entangled Diffraction†:

$$D_r = \frac{2.44\lambda}{2d_t} R$$

† M. D'Angelo, M.V. Chekhova and Y.H. Shih, "Two-photon Diffraction and Quantum Lithography" arXiv:quant-ph/0103035 v1 8 Mar 2001.

Single-photon vs. Entangled Two-Photon Diffraction Pattern JPL

Legend:
— Single-photon
— Two-photon

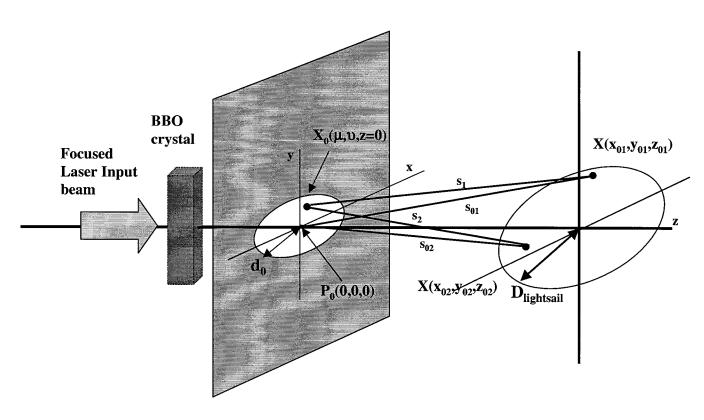## n-Photon Entangled Diffraction:*

$$D_r = \frac{2.44\lambda}{nd_t}R$$

* A. Lamas-Linares et.al. *Nature 412* (2001) 887.

Diffraction calculation using Huygens construction

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$$A\left(\vec{k}_{01}, \vec{k}_{02}\right) = \int \int \left[G_{1,k_1\beta_1} G_{2,k_2\beta_2} + G_{1,k_2\beta_2} G_{2,k_1\beta_1} \right] e_{\omega_1} e_{\omega_2} F\left(\vec{k}_1\beta_1, \vec{k}_2\beta_2\right) d\vec{k}_1 d\vec{k}_2$$
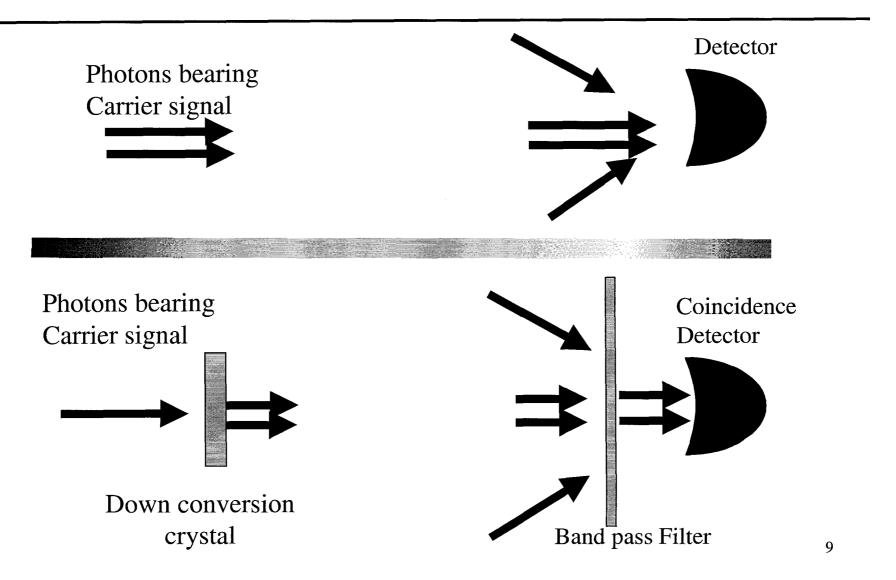
Second Order Probability Amplitude

1990, Javanainen and Gould predict startling result:

For parametrically driven photons at low intensities, two-photon transition rate is linear in I, not quadratic!

$$\left| A\left(\vec{k}_{01}, \vec{k}_{02} \right) \right|^2 = \left\langle \Psi \left| E_1^{(-)} E_2^{(-)} E_1^{(+)} E_2^{(+)} \right| \Psi \right\rangle \propto I$$

J. Javanainen and P.L. Gould, "Linear intensity dependence of a two-photon transition rate", Phys. Rev. A 41 (1990) 5088.

Common Mode Noise Rejection
of a Large Background Noise Source

Photons bearing
Carrier signal

Detector

Photons bearing
Carrier signal

Down conversion
crystal

Coincidence
Detector

Band pass Filter

Conclusions

- Diffraction advantage can't be realized for 1st order intensity detection.
- Diffraction peak narrows for second order coincidence detection.
- Similar narrowing observed with short pulses => improvement in clock synchronization possible.
- Low intensity detection rate is linear rather than quadratic.
- Possible applications for quantum entangled photons:
  - Common mode rejection detection schemes
  - Clock synchronization
  - Quantum lithography